P-2.3 Interpret the velocity or speed and acceleration of one and two-dimensional motion on distance-time, velocity-time or speed-time, and acceleration-time graphs

Revised Taxonomy Level 2.1 B Represent (interpret) conceptual knowledge

Key Concepts

In physical science, students represent selected types of motion with a distance-time graph when given either a verbal description of the motion or a data set describing the motion of the object.

- Types of motion represented:
  - Object at rest
  - Object with constant speed (direction constant)
  - Object with constant positive acceleration (direction constant)
  - Object with constant negative acceleration (direction constant)
- Students compare the shape of distance-time graphs for the following sets of objects
  - Two objects traveling at two different constant speeds (direction constant)
  - Two objects which are accelerating at different constant rates (direction constant)
- Students compare the shape of a displacement-time graph for two objects traveling in different directions at a constant speed. (students only consider the same or opposite direction)
- Students construct a distance-time graph depicting the motion of an object as described in a story. The story describes
  - Rest
  - Constant velocity (at various rates)
  - Acceleration

As Physics for the Technology classes and traditional college prep classes will have different curricula based on the choices that are made for standards six through ten, the scope of the core curriculum should vary as well. The emphasis of topics within the core standards will depend on subsequent topics to be addressed.

It is essential for all physics students to

- Create, interpret and analyze graphs of motion
  - Interpretation of a graph should include
    - Determination the slope of the graph and an understanding the meaning of the slope in terms of magnitude and direction of the motion
- Types of graphs should include
  - Position-time graphs
    - rest
    - constant velocity, (positive and negative direction)
    - positive and negative acceleration (positive direction)
  - Velocity-time graphs
    - rest
    - constant velocity
    - positive and negative acceleration (positive direction)

- Acceleration-time graphs
  - Constant velocity
  - Constant positive and negative acceleration (positive direction)

Physics for the technology differentiation

- Create, interpret and analyze force-time graphs

College prep differentiation

- Determine the slope and the area under the curve of a graph and understand the meaning of these in terms of magnitude and direction of the motion
- Create, interpret and analyze
  - Position-time graphs
    - constant velocity,
      - positive and negative direction, toward and away from the origin
    - positive and negative acceleration,
      - positive and negative direction, towards and away from the origin
  - Velocity-time graphs
    - Constant velocity, positive and negative direction
    - Positive and negative acceleration (positive and negative direction)

Assessment

As the verb for this indicator is interpret (represent) the major focus of assessment will be for students to "change from one form of representation to another", in this case, the motion of an object can be represented in three forms: verbal description, organized data, and graphical representation. When information about the motion of an object is given in any of the above three forms, students should be able to represent the motion of that object in the other two forms. It is not important that students know those specific graphs but, as this indicator is classified as conceptual knowledge, it is vital that students can apply their knowledge of graphical analysis of motion to any novel set of data, verbal description, or graphical analysis of motion.

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P-2.4 Interpret the resulting motion of objects by applying Newton's three laws of motion: inertia; the relationship among net force, mass, and acceleration (using F = ma); and action and reaction forces.

Revised Taxonomy Levels **2.1 B Represent (interpret) conceptual knowledge**
3.2 B Use (implement) conceptual knowledge
3.2 C_A Use (implement) procedural knowledge

Key Concepts

In Physical Science, students explain the motion of objects on the basis of Newton's three laws of motion: inertia; the relationship among force, mass, and acceleration; and action and reaction forces.

- Newton's First Law of Motion
  - Students are introduced to the concept of inertia,
    - Students are introduced to the Newton as the metric system unit for force
    - Students explain the relationship between mass of an object and its inertia,
    - Students describe the motion of familiar moving objects in terms of inertia
  - Students identify the net forces acting on familiar objects that are accelerating (slowing down, speeding up, or changing direction)
- Newton's Second Law of Motion
  - Students explored the relationship between the motion of an object, it mass, and the force exerted on it, in both sixth and eighth grades, however the concept of acceleration is first introduced in physical science.
    - The concept of net force is addressed in terms of an applied force and an opposing force (friction), or in terms of two applied forces in the same direction. Students identify each force from a story problem and solve for the net force. (In terms of forces applied in the same direction or in opposite directions, no vector problems).
    - Students are introduced to the equation $F_{net} = ma$
    - Students derive the Newton in terms of kgm/sec^2
    - The second Law equation is applied to the weight and mass of objects in terms of the acceleration on gravity ($F_w = ma_g$)
    - Students solve single-step word problems for any of the three variables (F_{net}, m, or a)
- Newton's Third Law of Motion
  - The emphasis in physical science is that the two forces discussed in this law do not cancel because they are not both exerted on the same object.
  - Students analyze and explain the motion of familiar objects (such as a swimmer moving forward by pushing the water backwards) in terms of all three laws.
  - Newton's Law of Universal Gravitation is addressed conceptually as an application of third law
    - Students are introduced to the idea that objects with larger masses exert more force, and objects that are closer together exert more force.
    - Students are introduced to the idea that the law applies to all objects, not just large objects like the earth.

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It is essential for all physics students to

- Interpret and apply Newton's First Law of Motion
- Assess, measure, and calculate the relationship among the force acting on a body, the mass of the body, and the nature of the acceleration produced (Newton's Second Law of Motion)
  - Multi-step problems should be included and may involve combinations of
    - Calculating acceleration from distance, velocity, and time data
    - Determining a net force from vector addition of two forces
    - Determining the mass of an object from its weight
- Interpret and apply Newton's Third Law of Motion
  - Students should identify action-reaction force pairs from diagrams or word problems
  - Students should describe the motion of familiar objects in terms of Newton's Third Law
  - Students should understand gravitation in terms of action reaction forces. If the earth exerts a force on an object the object exerts a force on the earth.
  - Students should apply the third law to solve word problems involving the force exerted on an object.

Physics for the technology differentiation

- Understand that pressured is force per unit of area ($P = F/A$)
  - Understand that the unit for pressure is the Pascal
    - One Pascal is equal to one Newton/meter-squared (N/m^2)
  - compare the pressure of objects with the same weight but in different orientations (an upright book on a table vs. the same book lying flat)
  - Solve problems involving force pressure and area

College prep differentiation

- Assess, and calculate the nature and magnitude of gravitational forces
  - Apply concepts to analyze the motion of satellites
- Understand an "inverse square law" and use the understanding to predict the new value of the masses, force, or distance when one or more of the values is changed.

Assessment

The verb for this indicator is interpret (represent) the major focus of assessment will be for students to "change from one form of representation to another", in this case, the motion of an object can be represented in three forms: verbal description, organized data, and graphical representation. When information about the motion of an object is given in any of the above three forms, students should be able to represent the motion of that object in the other two forms. As this indicator is classified as conceptual knowledge, it is vital that students can apply their knowledge of graphical analysis of motion to any novel set of data, verbal description, or graphical analysis of motion.

The verb implement (use), means that the other major focus of assessment will be for students to show that they can "apply a procedure to an unfamiliar task". Students will use two types of knowledge

- Procedural knowledge is "knowledge of subject-specific techniques and methods" In this case the procedures for solving problems involving force, mass and acceleration, including vector addition, graphing, and algebraic problem solving. The unfamiliar task is a novel word problem or a set of data. A key part of the assessment will be for students to show that they can apply the knowledge to a new situation, not just repeat problems which are familiar. This requires that students have a conceptual understanding of each of the laws of motion and an understanding of the effect that they have in combination.
- Conceptual knowledge is "the interrelationships among the basic elements within a larger structure that enable them to function together", in this case, Newton's Laws of Motion. Assessments must show that students can assess the motion of an object based on the influence of all three laws.

P-2.5 Explain the factors that influence the dynamics of falling objects and projectiles.

Revised Taxonomy Level 2.7 B Explain conceptual knowledge
Key concepts
Projectile motion

In physical science
- Students were introduced to the idea that all objects accelerate as they fall at the same rate, 9.8m/sec^2
- Students understand that the acceleration of gravity is a result of the gravitational force exerted by the earth.
- Students analyze the motion of a falling object during consecutive seconds of freefall in terms of
  - Initial velocity
  - Final velocity
  - Average velocity
  - Distance the object falls

As Physics for the Technology classes and traditional college prep classes will have different curricula based on the choices that are made for standards six through ten, the scope of the core curriculum should vary as well. The emphasis of topics within the core standards will depend on subsequent topics to be addressed.

It is essential for all physics students to
- Understand that objects projected upward experience the same gravitational force, and therefore the same acceleration as objects in free fall.
- Analyze the motion of an object projected directly upward
  - Students should be given the initial velocity of the object
  - Students should analyze consecutive seconds of motion for the complete trip (up and down) in terms of
    - Initial velocity
    - Final velocity
    - Average velocity
    - Distance traveled
- Analyze independently the vertical and the horizontal motion of a projectile which is projected upward at a 45° angle with the ground (ignoring air resistance)
  - Horizontal Motion
    - The object has an initial velocity in the horizontal direction
    - The object has a constant velocity (1st Law) equal to the initial velocity
    - The motion can be described as
      horizontal velocity = horizontal displacement/ time
  - Vertical Motion
    - The vertical motion is the same as an object which is projected straight upward
    - Going up

        - The object has an initial vertical velocity
        - The object is slowing down due to the acceleration of gravity
        - The final velocity of the object is zero (going up)
        - $-9.8 m/s^2 = (0 m/s - \text{vertical } v_i) / t$
    - Going down
        - The object has an initial velocity of zero
        - The object is speeding up due to the acceleration of gravity
        - The object has a final velocity right before it hits the ground (which has same value as the initial velocity the object had when it began going up)
        - $9.8 m/s^2 = (\text{vertical } V_f - 0 m/s) / t$
    - The time going up equals the time going down.
  - The time for the horizontal trip is equal to the total time for the vertical trip.
- Understand that the implication of this analysis is that projectiles hit the ground at the same time as objects that have not vertical motion.
- Use this knowledge to determine how changing each variable will effect the other variables for example, how does the initial vertical velocity effect the horizontal distance that a projectile travels.

College prep differentiation

- Understand that the initial velocity of a projectile (directed at the actual angle that the projectile is traveling) has a vertical and a horizontal component
  - Understand that the vertical component of the velocity is the initial velocity as it goes up
  - Understand that the horizontal component of the velocity is the object's the constant vertical velocity

Assessment

As the verb for this indicator is explain the major focus of assessment will be for students to "construct a cause and effect model". In this case, assessments will ensure that students can model how the velocity and the displacement of an object vary with time as an object is project upward, falls, or has trajectory motion.

Because the indicator is written as conceptual knowledge, assessments should require that students understand the "interrelationships among the basic elements within a larger structure that enable them to function together." In this case, assessments must show that students can construct a cause and effect statement relating how the velocity and the displacement of an object vary with time as the object rises or falls.

P-2.6 Apply formulas for velocity and acceleration to solve problems related to projectile motion.

Revised Taxonomy Level **3.2 C_A** **Apply (implement) procedural knowledge**
Key Concepts

Physical science students did not address projectile motion

As Physics for the Technology classes and traditional college prep classes will have different curricula based on the choices that are made for standards six through ten, the scope of the core curriculum should vary as well. The emphasis of topics within the core standards will depend on subsequent topics to be addressed.

It is essential for all physics students to

- Apply all of the concepts and formulas used to analyze accelerated motion to objects in free fall and projectiles.
  - Solve problems involving falling objects, or objects projected upward
    - $a_g = (v_f - v_i)/t$
    - $d = (v_{ave})\ t$
    - $v_{ave} = (v_i + v_f)/2$
  - Solve problems involving the upward vertical motion of a projectile and the downward vertical motion of a projectile
    - $a_g = (v_f - v_i)/t$
    - $d = (v_{ave})\ t$
    - $v_{ave} = (v_i + v_f)/2$
  - Solve problems involving the horizontal motion of a projectile
    - $v = d/t$
  - Graph the vertical and the horizontal motion of falling objects and trajectories

College prep differentiation

- Use vector analysis to determine the vertical and horizontal components of the initial velocity of a projectile.

Assessment

As the verb for this indicator is implement (use), the major focus of assessment will be for students to show that they can "apply a procedure to an unfamiliar task". The knowledge dimension of the indicator, procedural knowledge means "knowledge of subject-specific techniques and methods" In this case the procedure is the application of the equation for constant velocity and the equations which apply to accelerated motion. The unfamiliar task should be a novel word problem or laboratory investigation. A key part of the assessment will be for students to show that they can apply the knowledge to a new situation, not just repeat problems which are familiar. This requires that students have a conceptual understanding of each of the variables as well as mastery of the skills required to implement the mathematical equation or in order to solve the problem.

P-2.7 Use a free-body diagram to determine the net force and component forces acting upon an object.

Revised Taxonomy Level **3.2 C_A Apply (use) procedural knowledge**

Key Concepts

Effective force

- In Physical science students determined the net force acting on an object only in the case of forces acting in the same or opposite directions.
- Students were not required to represent the forces in vector diagrams.

As Physics for the Technology classes and traditional college prep classes will have different curricula based on the choices that are made for standards six through ten, the scope of the core curriculum should vary as well. The emphasis of topics within the core standards will depend on subsequent topics to be addressed.

It is essential for all students to

- Illustrate the forces acting on an object using a vector diagram when given a verbal description or data.
  - Draw force vectors in the appropriate direction and representing the magnitude of the force
  - The effective forces (forces which influence the motion) are in the same or the opposite direction of the motion.
  - If any of the given forces are not in the same or opposite direction as the motion but have a component in the same or opposite direction as the motion,
    - use vector analysis to determine the magnitude of the effective component of the given force (either analytically or by graphic analysis)
    - draw the effective component of the force
  - From the diagram, determine the magnitude and direction of the net force acting on an object
  - Use the net force to solve problems involving the motion of the object
  - Examples include
    - An object being pulled horizontally with friction opposing the motion
    - An object (like a lawn mower) being pushed at a particular angle with the ground, with friction opposing the motion.
    - An object (like a lawn mower) being pulled at a particular angle with the ground, with friction opposing the motion.
    - An object projected upward with a constant force (such as a rocket engine) with the gravitational force opposing the motion

College prep differentiation

- Consider
  - Objects sliding down a ramp with friction opposing the motion
  - Objects being pulled up a ramp with friction opposing the motion

Assessment
As the verb for this indicator is implement (use), the major focus of assessment will be for students to show that they can "apply a procedure to an unfamiliar task". The knowledge dimension of the indicator, procedural knowledge means "knowledge of subject-specific techniques and methods" In this case the procedure for using a free body diagram to determine the net force acting on an object and the equations which apply to the motion of an object. The unfamiliar task should be a novel word problem or laboratory investigation. A key part of the assessment will be for students to show that they can apply the knowledge to a new situation, not just repeat problems which are familiar. This requires that students have a conceptual understanding of each of the forces and an understanding of how the components of a force are related to the resultant force. Mastery of the skills required to implement the mathematical equations in order to solve the problem are also essential procedures.

P-2.8 Distinguish between static and kinetic friction and the factors that affect the motion of objects

Revised Taxonomy Level **4.1B** **Differentiate (distinguish) conceptual knowledge**
Key Concepts
Static (limiting) frictional force
Kinetic (dynamic) frictional force
Coefficient of friction (μ)

In physical science, students define friction as a force opposing motion.
They do not distinguish between static and kinetic friction.

It is essential for students to

- Qualitatively and quantitatively compare static friction and kinetic friction
  - Students should understand that friction is caused by the intermolecular force between the molecules of two surfaces
  - Students should understand that static (limiting) friction is the maximum value of the frictional force between two surfaces. It occurs when the two surfaces are on the point of sliding over each other.
  - Students should understand that kinetic (dynamic) friction is the value of the frictional force when one surface is sliding over another at constant speed. It is slightly less than static friction.
  - Students should understand the factors that affect friction
    - Normal force (f_n) (the net force perpendicular to the surface)
    - The physical properties of the two substances
    - The chemical properties of the two substances
  - Students should understand that the ratio between the frictional force between two surfaces to the force that is pushing them together (the normal force) is called the coefficient of friction.
    - The coefficient of sliding friction is slightly different from the coefficient of static friction for any given combination of substances
    - Both the coefficient of sliding friction and the coefficient of static friction are constant for a particular combination of substances
  - Students should use the equation $\mu = f_f / f_n$ to solve problems involving the motion of objects

Assessment

As the verb for this indicator is differentiate (distinguish), the major focus of assessment should be for students to distinguish between the relevant and irrelevant parts or important from unimportant parts of presented materials. Because the verb is differentiate rather than compare, students should assess the motion of an object in order to determine the factors that are important in determining the effect of friction (both static and kinetic) on an object. Students can use a free body diagram and their knowledge of the laws of motion in order to determine the normal force or the frictional force exerted by an object.

P-2.9 Explain how torque is affected by the magnitude, direction, and point of application of force

Revised Taxonomy Level 2.7 B Explain conceptual knowledge
Key concepts
Torque
Center of gravity
Torque arm

Students did not explore rotational motion in physical science

As Physics for the Technology classes and traditional college prep classes will have different curricula based on the choices that are made for standards six through ten, the scope of the core curriculum should vary as well. The emphasis of topics within the core standards will depend on subsequent topics to be addressed.

It is essential for students to
- Understand that translational equilibrium occurs when all of the forces are balanced, meaning the object will not accelerate.
- Understand that torque (moment of inertia) is influenced by force, direction, and point of application.
- Understand that unbalanced torque produces rotation
- Understand that torque is
  - force applied with leverage,
  - torque is force applied over a distance
  - torque = force x lever arm ($\tau = fd$)
- Understand that rotational equilibrium occurs when torques are balanced, meaning the object will not rotate
- Understand the concept of center of gravity
- Solve problems involving the concept of torque
- Understand the difference in rotation and revolving

Assessment
As the verb for this indicator is explain the major focus of assessment will be for students to "construct a cause and effect model". In this case, assessments will ensure that students can model how the application of torque (in terms of force, direction, and length of torque arm) affects the motion of an object.

Because the indicator is written as conceptual knowledge, assessments should require that students understand the "interrelationships among the basic elements within a larger structure that enable them to function together." In this case, assessments must show that students can construct a cause and effect statement relating how various applied torques affect the motion of an object

P-2.10 Explain the relationships among speed, velocity, acceleration, and force in rotational systems

Revised Taxonomy Level 2.7 B Explain conceptual knowledge
Key concepts
Angular displacement
Angular velocity
Angular acceleration
Angular momentum

Physical science students did not study rotational systems

As Physics for the Technology classes and traditional college prep classes will have different curricula based on the choices that are made for standards six through ten, the scope of the core curriculum should vary as well. The emphasis of topics within the core standards will depend on subsequent topics to be addressed.

It is essential for students to

- Understand that rotational motion is the motion of an object about an internal axis
- Angular displacement (θ) can be measured in units of revolutions
- Angular velocity (ω) can be measured in units of revolutions per second
- Angular acceleration (α) can be measured in units of revolutions per second-square
- Rotational inertia (I) is the resistance of a rotating object to changes in its angular velocity
  - Another name for rotational inertia is "moment of inertia"
  - The formula for the rotational inertia of an object varies with its shape but in all cases, rotational inertia is directly proportional to the mass of the object and to its diameter (or length).
- Newton's Second Law of Motion in terms of rotary motion states that when an unbalanced torque is applied to an object the object will experience angular acceleration.
  - The rate of the angular acceleration is directly proportional to the torque
  - The rate of the angular acceleration is inversely proportional to the rotational inertia of the object.
  - As such, the smaller the diameter (or length) of an object, the greater the angular acceleration a given torque will produce. (Reference ice-skater spins)

- The equations for linear motion can be applied to rotational systems

	Linear Motion	Rotary Motion
Constant velocity	$v = d/t$	$\omega = \theta/t$
Average velocity (regardless of type of motion)	$v_{ave} = \Delta d/\Delta t$	$\omega_{ave} = \Delta \theta /\Delta t$
Constant acceleration	$a = (v_f - v_i)/t$	$\alpha = (\omega_f - \omega_i)/t$
	$d = (v_{ave})\, t$	$\theta = (\omega_{ave})\, t$
	$v_{ave} = (v_i + v_f)/2$	$\omega_{ave} = (\omega_i + \omega_f)/2$
Newton's Second Law	$F = ma$	$T = I \alpha$

- ❖ Solve problems involving torque, angular inertia, angular displacement, angular velocity, and angular acceleration.

Assessment

As the verb for this indicator is explain the major focus of assessment will be for students to "construct a cause and effect model". In this case, assessments will ensure that students can model how the motion in linear systems is similar to motion in rotational systems.
Because the indicator is written as conceptual knowledge, assessments should require that students understand the "interrelationships among the basic elements within a larger structure that enable them to function together." In this case, assessments must show that students can construct a cause and effect statement relating the laws of motion to rotational systems.